How to use line sweeping to maintain antenna systems

Two types of line sweeping equipment are suitable for feedline and antenna system measurements that detect deterioration and faults. Sample waveforms help to show you how to interpret test results.

By James M. Crooks

There appears to be a lot of confusion in the communications industry concerning transmission lines, antennas, connectors, waveguides and when and where to use time-domain reflectometers (TDRs) and frequency-domain reflectometers (FDRs).

The right information helps to dispel some of the misconceptions and helps technical supervisors to make important decisions about antenna system maintenance.

TDR

A TDR works on the same principal as radar: Pulses are transmitted down the cable under test and a part or most of the pulse energy is reflected.

The time required for the pulse to reflect and return to the source can be measured and plotted to provide a meaningful indication.

Time domain reflectometry is useful in three main areas of feedline and antenna system work:

- *Design*—It identifies impedance discontinuities.
- *Assembly and testing*—It aids in tuning.
- *Installation and maintenance*—It helps in fault location.

Crooks is president of Broadcast Communications, New Glarus, WI. He is a former chairman of the Wisconsin State 9-1-1 Board. He has been in the communications industry for 37 years, designing and installing systems for a wide variety of users.

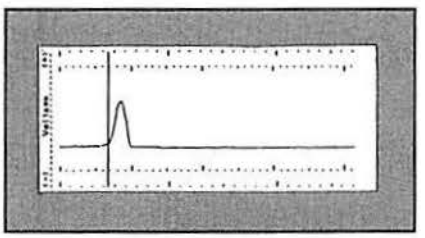

Figure 1. A properly TERMINATED cable absorbs the TDR signal, resulting in no reflection. Faults located ahead of the termination may be revealed as reflections along the waveform. If a terminator causes a reflection, the termination may be bad.

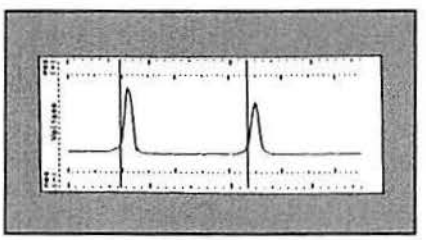

Figure 2. A reflection with the same polarity indicates a fault with OPEN (high impedance) tendencies. The reflection shown at the second cursor is a COMPLETE OPEN.

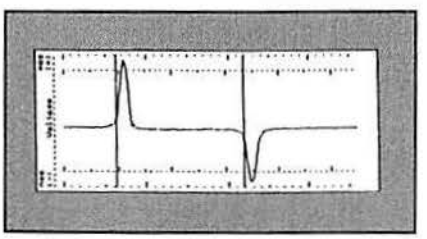

Figure 3. A reflection with the opposite polarity indicates a fault with short (low impedance) tendencies. The reflection shown at the second cursor is a DEAD SHORT.

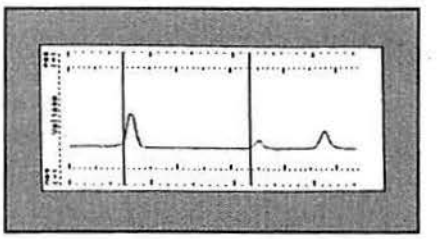

Figure 4. The middle reflection at the second cursor is a PARTIAL OPEN followed by a COMPLETE OPEN (end of the cable). The more severe the fault, the larger the reflection.

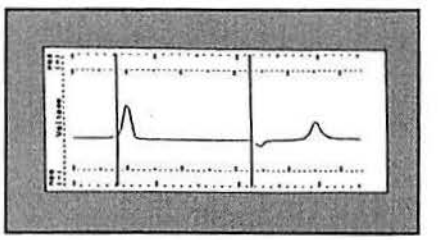

Figure 5. The middle reflection at the second cursor is a PARTIAL SHORT followed by a COMPLETE OPEN (end of the cable). The more severe the fault, the larger the reflection.

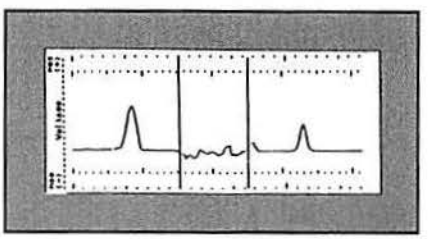

Figure 6. A water-soaked cable displays a waveform with a downward slope, indicating the beginning of the water, and an upward rise at the end of the water. Generally, the area in between the two reflections appears 'noisy'.

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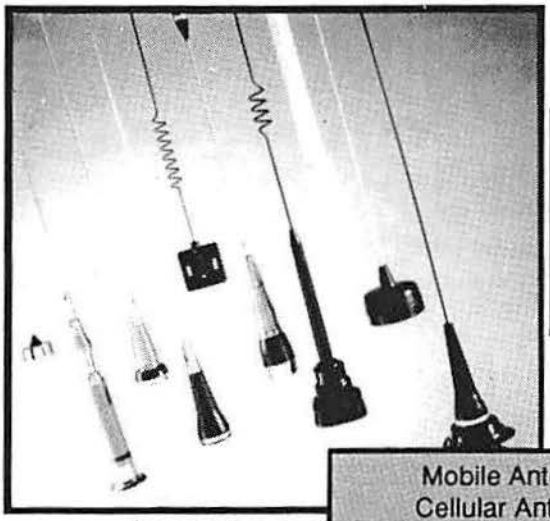

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Installation and maintenance is the most common use of a TDR.

Source pulse

The source pulse amplitude and duration determine its energy content and the maximum cable or line length that can be measured.

Pulse amplitude usually is fixed by the manufacturer and cannot be changed by the operator. Pulse width usually is adjustable via a preselection control that allows the operator flexibility.

The wider the pulse, the longer the feedline that can be accurately measured. There is a trade-off, though: A *blind spot* at the beginning of the pulse can mask discontinuities.

With a 2nS (2 nanoseconds or two billionths of a second) pulse, the blind spot covers approximately 3 feet; a

The source pulse amplitude and duration determine its energy content and the maximum cable or line length that can be measured.

10nS pulse has a 15-foot blind spot; and a 1,000nS pulse has a 600-foot blind spot. No return pulses are evident in the blind spot, so no faults are displayed within those sections of feedline.

One way to overcome the blind spot is to insert a jumper cable equal to the blind spot length between the TDR and the feedline to be measured. With a 2nS pulse, the jumper is 3 feet long. To calculate the distance to a fault or the feedline length, jumper cable length is subtracted from the TDR fault indication.

Reflected pulse

The reflected pulse amplitude always is less than the source pulse

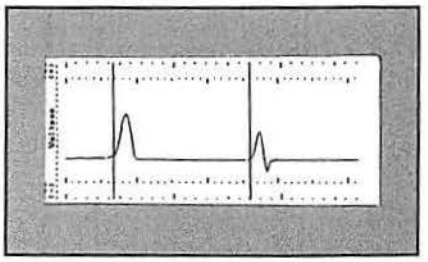

Figure 7. A HIGH RESISTANCE JOINT or SPLICE produces an *S-shaped* reflection. A high-impedance UPWARD reflection is followed by a lower-impedance DOWNWARD reflection.

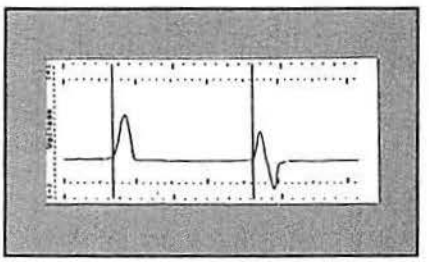

Figure 8. Testing through to an antenna usually results in an *S-shaped* reflection, although reflections can vary greatly depending on the antenna.

amplitude because of signal loss in the cable.

Keep in mind that the outgoing pulse is attenuated by line loss, and the *return* or *reflected* pulse is attenuated by the same amount.

Most TDRs present a positive-going source pulse, and the reflected pulse is either plus or minus, depending upon the return pulse's phase. Assuming a 50Ω source impedance, a positive return pulse indicates a reflected impedance greater than 50Ω (partial open or complete open of cable), and a negative return pulse indicates a reflected impedance less than 50Ω (kinks or water in the line or a partial short).

No reflection normally indicates a perfect 50Ω load that absorbs all of the pulse energy. An antenna connected to the line generally displays both a positive- and a negative-going pulse depending upon the antenna design and operating frequency.

TDR limits

Four important limitations should be

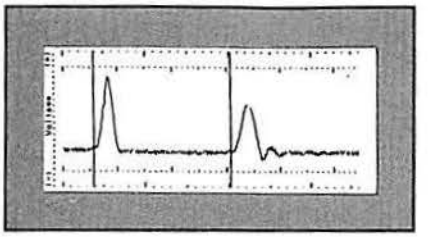

Figure 9. Testing tower cables with antennas can be challenging because of energy induction from high-RF areas as shown on the waveform. Stepping through various noise filter settings results in a cleaner waveform.

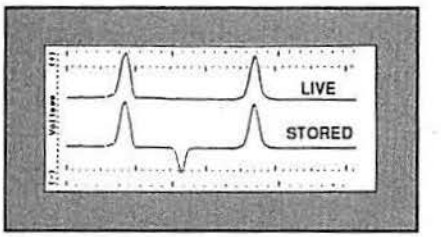

Figure 10. Some TDRs store images to allow an operator to compare the initial trace with another trace made after making a repair and print both traces as a permanent record.

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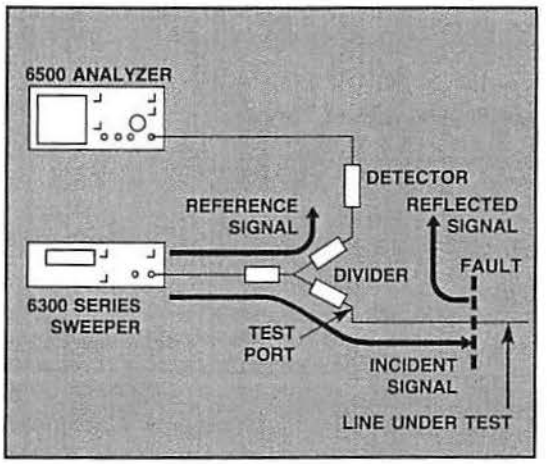

Figure 11. A scalar FDR setup block diagram for measuring distance to fault.

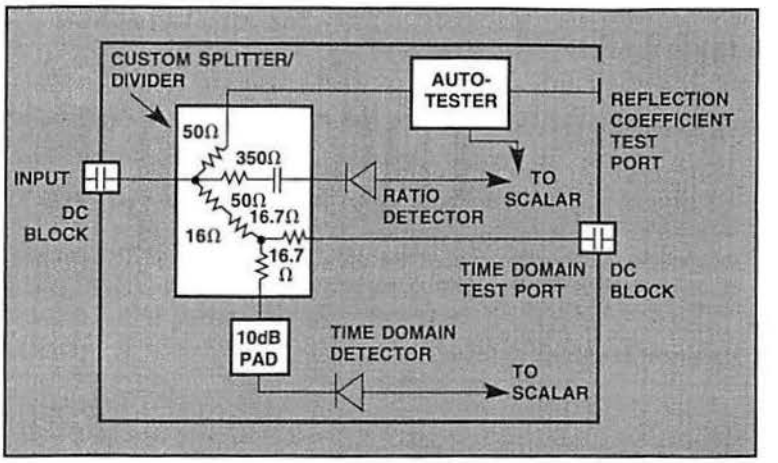

Figure 12. A scalar FDR setup block diagram for a directional coupler test head.

considered when using a TDR:

(1) The transmission line is pulsed at the TDR's pulse frequency, not at coaxial feedline's operating frequency. Some line faults are frequency-sensitive and may not be detected by a TDR.

(2) An antenna cannot be checked for resonant frequency by a TDR.

(3) Waveguide cannot be measured by a TDR because of the waveguide's dispersion effects.

(4) The actual return loss of a coaxial line cannot accurately be measured by a TDR.

Although a TDR has limitations when used with radio communications systems, it provides sufficient information in as much as 80% of transmission line applications, including:

- ▶ fault location.
- ▶ line length.
- ▶ types of faults.

Most TDRs are smaller than a briefcase. They usually are fitted with rechargeable batteries and a printer. The cost for most units ranges from $2,000

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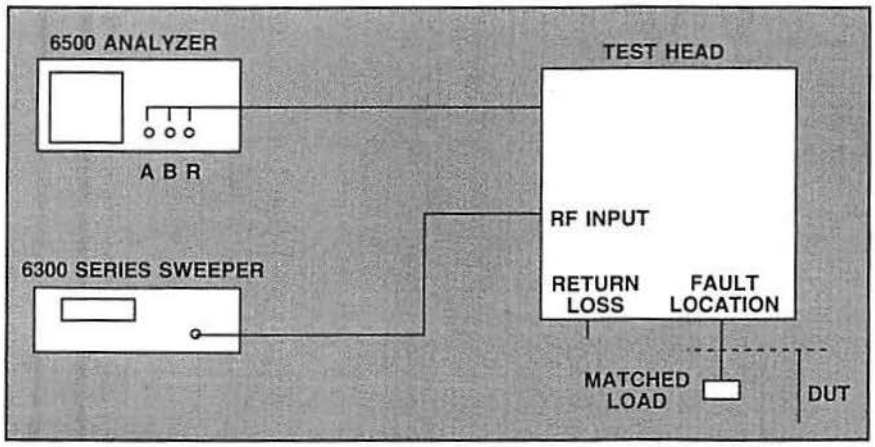

Figure 13. A scalar FDR setup block diagram for making insertion loss, return loss, VSWR, and antenna resonance measurements.

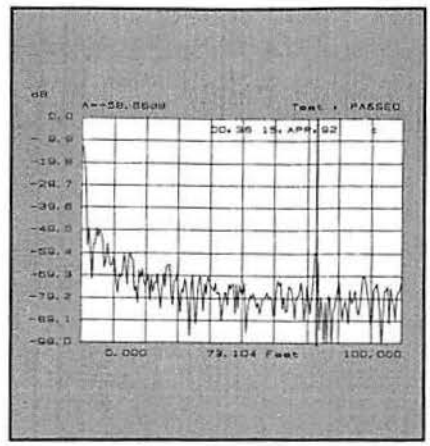

Figure 14. A typical plot of distance to fault of a transmission line.

to $5,000.

The display can be as simple as a footage counter or as elaborate as a liquid crystal display (LCD) or oscilloscope image. Some TDRs store images to allow an operator to compare the initial trace with another trace made after making a repair and to print both traces as a permanent record. (See Figure 10 on page 32.)

Sample waveforms

Sample TDR waveforms show the operator what to expect on the display. For example, Figures 1-10 show:

(1) a properly terminated cable.
(2) an open cable.
(3) a shorted cable.
(4) a partial open.
(5) a partial short.
(6) a water-soaked cable.
(7) a high-resistance joint or splice.
(8) an antenna connected to cable.
(9) RF energy on cable (use filter).
(10) dual trace, with both *storage* and *live* traces displayed.

The 10 waveforms show only a small example of the many types an operator is likely to see.

A good approach is to obtain and read the TDR instruction manual to become familiar with the specific unit being used.

Nevertheless, they represent the most common waveforms found in coaxial cable testing. The operator should become acquainted with the TDR and its various displays by experimenting with a variety of cables under simulated conditions. A good approach is to obtain and read the TDR instruction manual to become familiar with the specific unit being used.

FDR

A frequency-domain reflectometer works on the basis of a frequency-sweep generator: A sample of sweep generator signal is used to calibrate a *scalar analyzer* or *tracking generator*.

A directional coupler separates the

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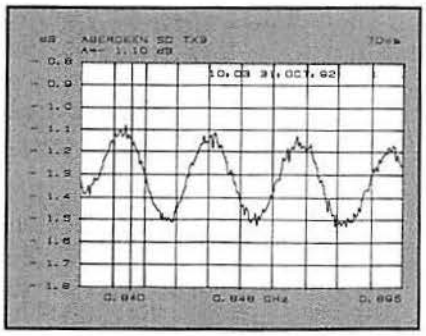

Figure 15. A typical plot of transmission line return loss.

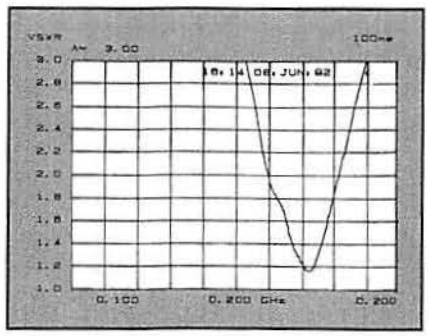

Figure 16. A transmission line VSWR plot.

outgoing sweep from the reflected sweep. A properly designed FDR with scalar data can provide the following information:

(1) spectrum analysis.
(2) insertion loss.
(3) fault location.
(4) antenna resonance.
(5) return loss (voltage standing wave ratio or VSWR).
(6) group delay.

The most commonly required measurements are spectrum analysis, insertion loss, fault location and antenna resonance.

▶ *Spectrum analysis*—A scalar FDR allows a frequency sweep of a transmission line, an antenna or both to display frequency-related problems in the line or antenna.

Antenna resonance is displayed to determine whether the antenna is defective or tuned to the proper frequency. A predetermined sweep range is selected, and any external signals being received by the antenna can be identified for receive level and frequency.

▶ *Insertion loss*—Insertion loss can be determined if both ends of a cable are available to measure the cable loss directly at the required operating frequency.

Loss in a jumper cable, connector, duplexer or combiner can be directly measured with the scalar FDR.

▶ *Fault location*—Although a TDR locates transmission line faults, it cannot measure the fault over a frequency spectrum, only time. (See Figure 11.)

A scalar FDR using the Fourier transform relationship can measure fault location at any predetermined frequency. This capability is extremely important at higher frequencies where cable connectors can affect VSWR greatly.

The FDR does not have a blind spot; the TDR is limited by the blind spot.

▶ *Antenna resonance*—The scalar FDR generates a curve of the frequency sweep and indicates the return loss or VSWR at all sweep frequencies; therefore, the antenna's resonant frequency is plotted, as well as the return loss.

Good engineering practice dictates that repeating the sweeps every year helps to detect deterioration or increased return loss.

▶ *Return loss*—Perhaps one of the most important and popular measurements, *return loss*, allows the operator to measure the amount of line loss directly at any operating frequency.

This loss can be checked against the calculated loss provided by the cable manufacturer. This test determines the cable's condition and measures return loss accurately. The operator must know the operating frequency, cable length and cable velocity of propagation (VOP).

From the amount of return loss, the operator can calculate or directly read the VSWR or the *voltage reflection coefficient* of the cable. The smaller the VSWR reading, the better the cable and load impedances match.

Figures 12-18 show the block diagram of the directional coupler test head for a scalar FDR; the block diagram of the scalar FDR setup for making insertion loss, return loss, VSWR and antenna resonance measurements; and several typical test plots.

Other information

Typically, TDR measurements are used for frequencies as high as 450MHz on coaxial cables, which covers as much as 80% of the applications.

Above 800MHz and at microwave frequencies, the FDR is highly preferred.

A scalar FDR costs $40,000 to $60,000, which is a substantial investment for a smaller company. Most companies contract a line sweeping service to check feedlines when they are installed.

Good engineering practice dictates that repeating the sweeps every year helps to detect deterioration or increased return loss. Early detection allows repairs and replacements to be scheduled before a serious loss occurs.

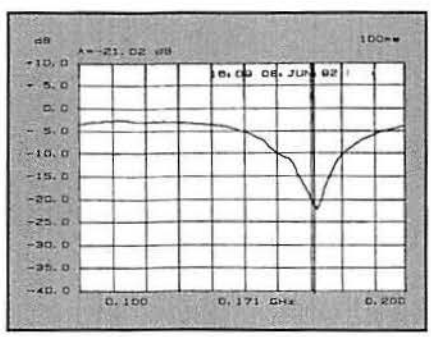

Figure 17. An antenna resonance plot.

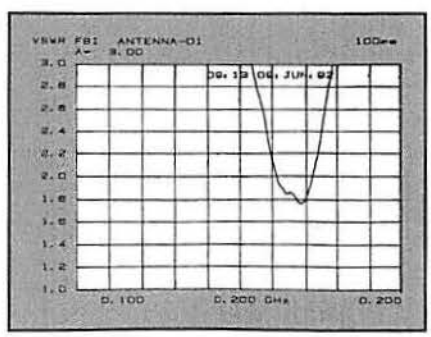

Figure 18. An antenna VSWR plot.